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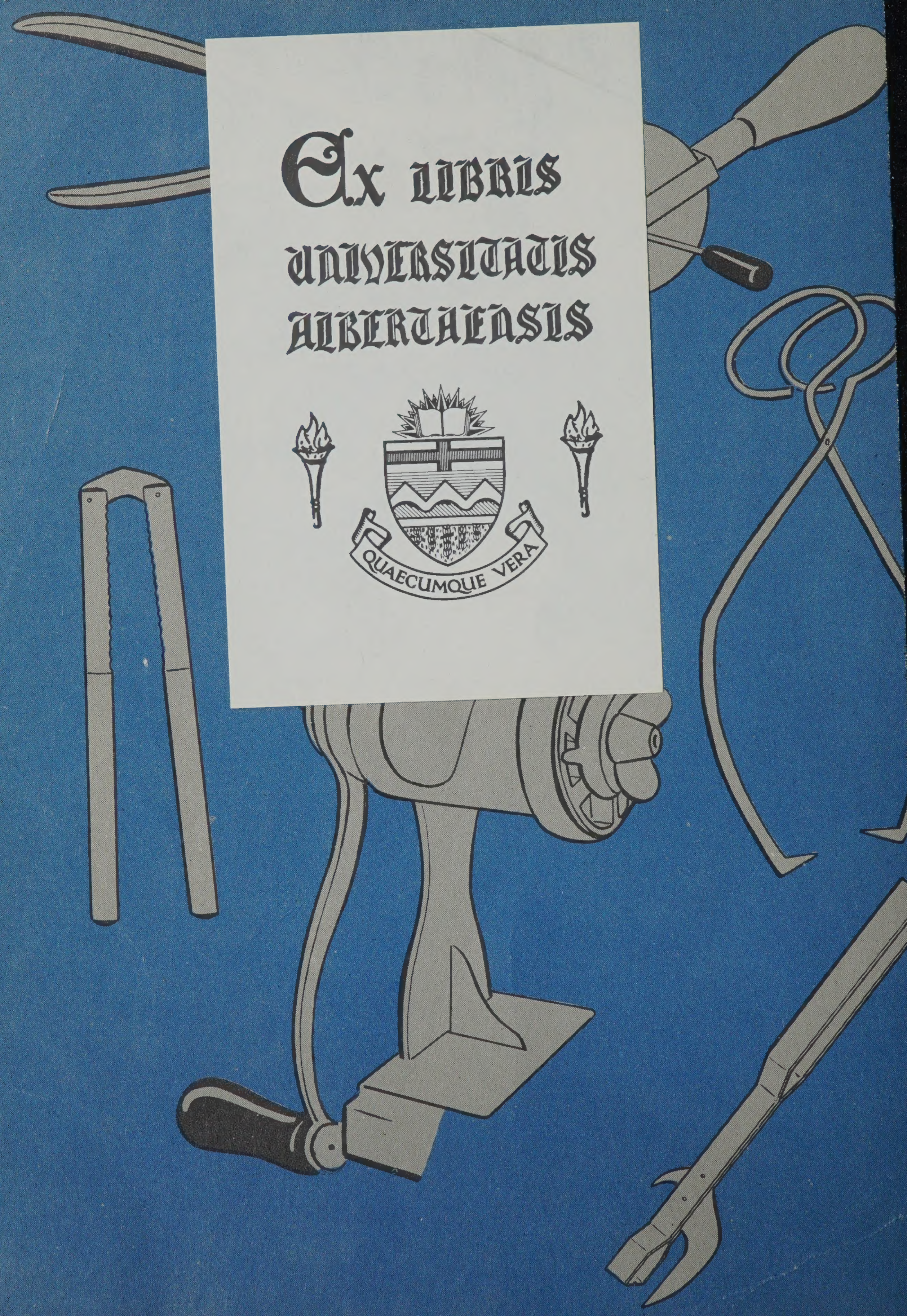

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Machines

A Tree House

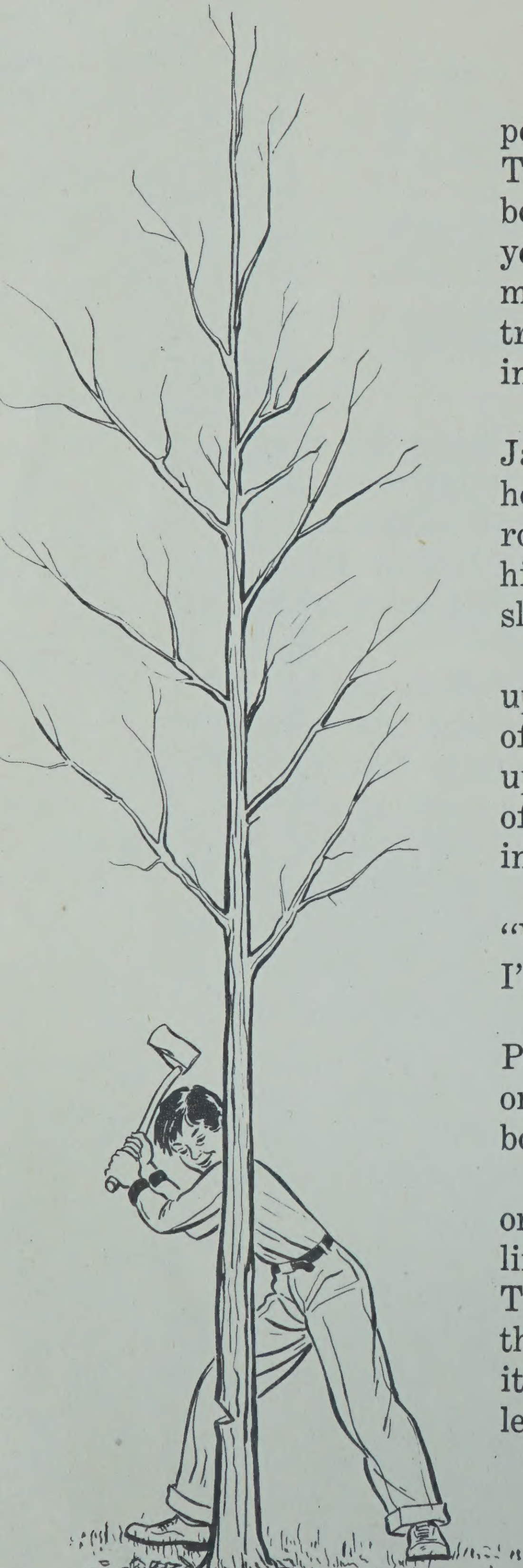
BOB and Jack had wanted a tree house for a long time. Now they had one. Their father was having a new garage built, and he had bought lumber for their tree house along with the lumber for the garage. The boys had done most of the work on the tree house themselves.

The tree house had two stories. The first story was a platform about ten feet above the ground. The second story was a smaller platform about eight feet higher in the tree. Each of the platforms had a railing around three sides.

Now the boys were ready to put on the finishing touches and move up the furniture they wanted. One of the pieces of furniture was a wooden chest they had made. It was meant to hold books and pillows and other things rain might spoil.

The chest had rollers at the corners. The boys rolled it out to the foot of the tree. But then they were puzzled. How were they going to get the chest up to the tree house?

Of course they could not climb the tree and carry it. They had a rope, but the chest was rather heavy. Pulling it straight up would be hard. Besides, there was the danger that the chest might slip out of the loop of rope around it and fall.



Soon the boys made a plan. The carpenters had not finished the garage. The boys borrowed some of the long boards the carpenters had not used yet. They nailed them together to make a sloping pathway up to the tree house. You can see the pathway in the picture on page 2.

The boys tied a rope to the chest. Jack climbed the tree to the tree house. Bob threw him the end of the rope. Then Bob climbed up to help him pull. The chest rolled up the sloping pathway easily.

"I wish we could leave the pathway up to our house," Jack said. "We'll often want things that we can't carry up. Right now let's make a big pail of lemonade and pull it up the slope in our wagon."

One of the carpenters heard him. "What you boys need is a windlass. I'll help you make one."

The boys had never seen a windlass. Perhaps you never have. The picture on page 2 shows the windlass the boys built. Jack is turning the crank.

When the boys turned the crank one way, the rope was wound up. It lifted whatever was fastened to it. Turning the crank the other way let the rope unwind. With the windlass it was very easy to pull up a pail of lemonade or a basket of lunch.

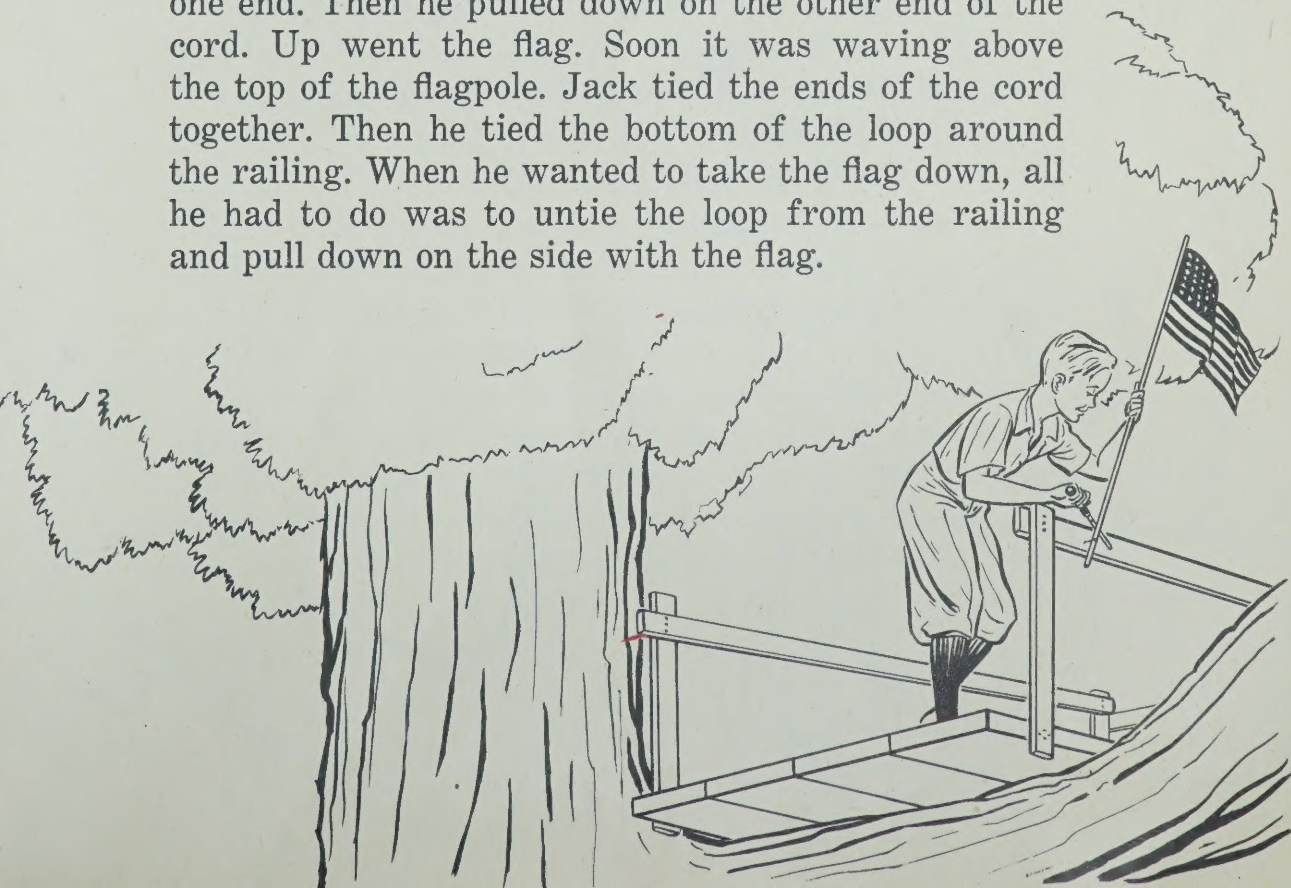
The next step was to put up their flag. The flag was fastened to a stick. Bob climbed to the second story of the tree house and nailed the flag stick to the railing. But the boys decided that the flag should be higher. They needed a flagpole.

In their back yard there was a small tree that was dying. The boys agreed that this little tree would make a good flagpole.

Bob cut the tree down with an axe and chopped off all the branches. The trunk of the tree made a tall, slender flagpole.

Before they nailed the flagpole in place, they fastened a little pulley to the top of it. They ran a long cord through the pulley. The cord was about ten yards long. When the flagpole was nailed to the railing, the pulley was ten feet above the platform.

With a screw driver Jack pried the flag stick from the railing. He tied it to the cord about ten feet from one end. Then he pulled down on the other end of the cord. Up went the flag. Soon it was waving above the top of the flagpole. Jack tied the ends of the cord together. Then he tied the bottom of the loop around the railing. When he wanted to take the flag down, all he had to do was to untie the loop from the railing and pull down on the side with the flag.



Putting their toy windmill in place came next. The boys decided to put it on the railing of the second story of their house. Jack started to nail it on. Then he stopped.

"If I nail this on, the wood may split," he said. "I have a better idea. I'll get the clamp I used to use to hold my pencil sharpener on my desk. Then I'll clamp it on."

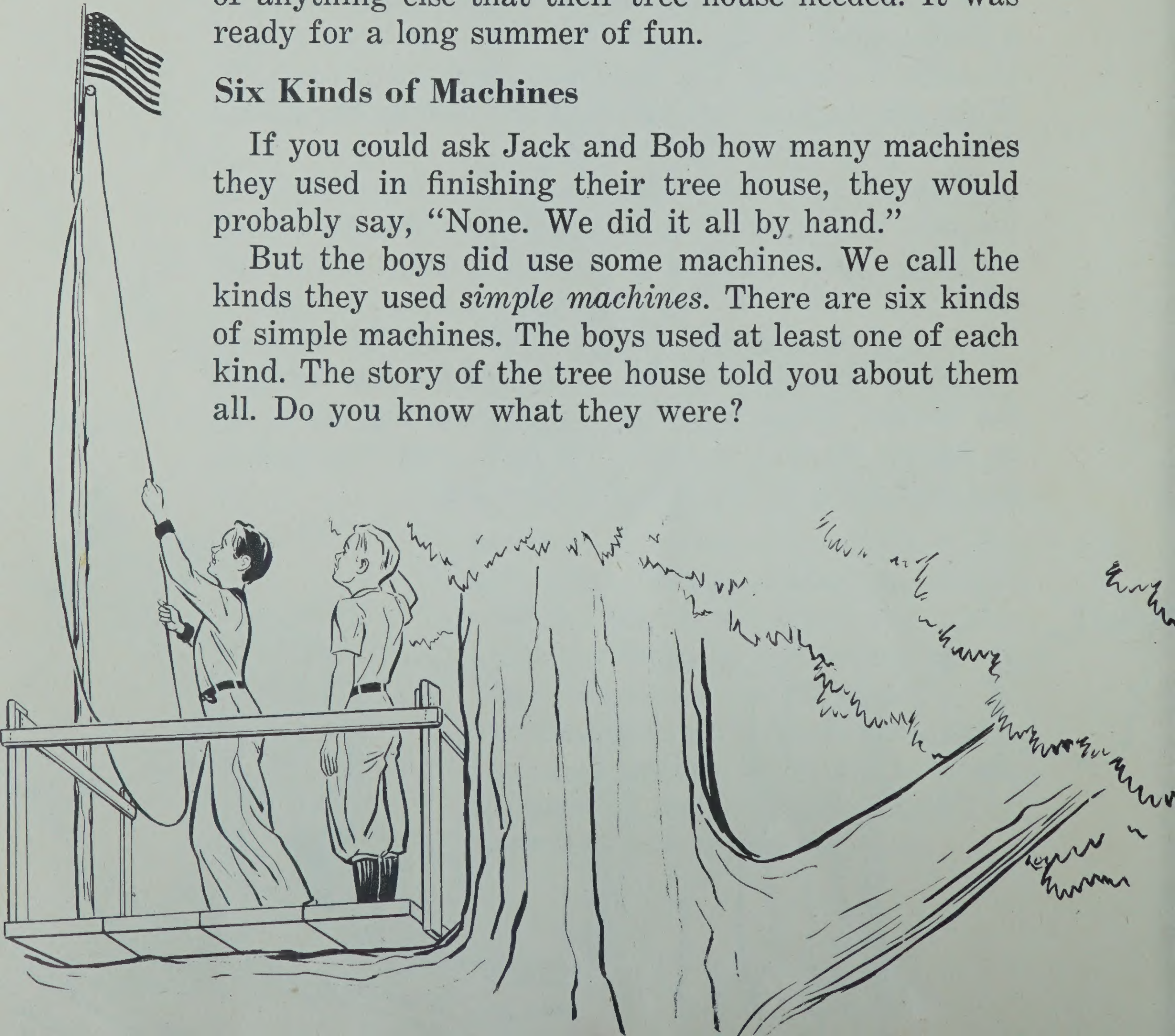
The clamp worked very well. It held the little windmill firmly in place.

With the windmill in place, the boys could not think of anything else that their tree house needed. It was ready for a long summer of fun.

Six Kinds of Machines

If you could ask Jack and Bob how many machines they used in finishing their tree house, they would probably say, "None. We did it all by hand."

But the boys did use some machines. We call the kinds they used *simple machines*. There are six kinds of simple machines. The boys used at least one of each kind. The story of the tree house told you about them all. Do you know what they were?



The slope they built of boards was an *inclined plane.* The inclined plane is the simplest of the six kinds of simple machines.

The windlass was a *wheel and axle.*

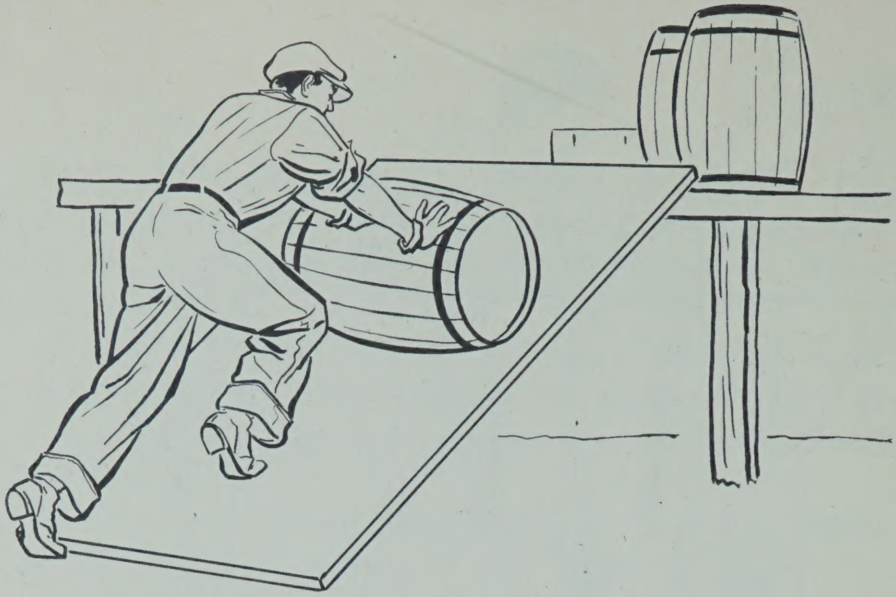
The axe Bob used to cut down the tree was a *wedge.* The nails the boys used were wedges, too.

The screw driver Jack used to pry the flag stick off the railing was also a machine. A screw driver can be used in different ways. Jack was using it as a *lever.*

The little *pulley* the boys fastened to the top of the flagpole was another of the simple machines they used.

The moving part of the clamp Jack used to hold the windmill in place was a *screw.*

All these things the boys used were machines, because they all helped the boys move something. Nothing can be called a machine unless it helps push things apart or pull them together or move them from one place to another. When we move anything in these ways we are *working.* Machines, then, help us work. How they do we shall now find out.



Inclined Planes

Bob and Jack found that it was easy to pull the chest up the slope they had built to their tree house. They did not have to pull so hard as they would have had to pull to lift it straight up. They did not have to use so much *force.*

An inclined plane always helps in the same way. It always helps save force.

But an inclined plane does not give us something for nothing. It simply lets us trade one thing for another. Can you see what we are trading for force when we use an inclined plane?

It is *distance.* We have to move whatever we are moving a longer way. It was only ten feet from the ground straight up to the tree house. But the sloping pathway was sixteen feet long.

The man in the picture is rolling a barrel up an inclined plane to a platform. The barrel is too heavy for him to lift. But he can roll it up the slope. The inclined plane lets him move the barrel with less force.

Suppose the barrel was so heavy that even with the inclined plane the man could not roll the barrel up to the platform. What could he do?

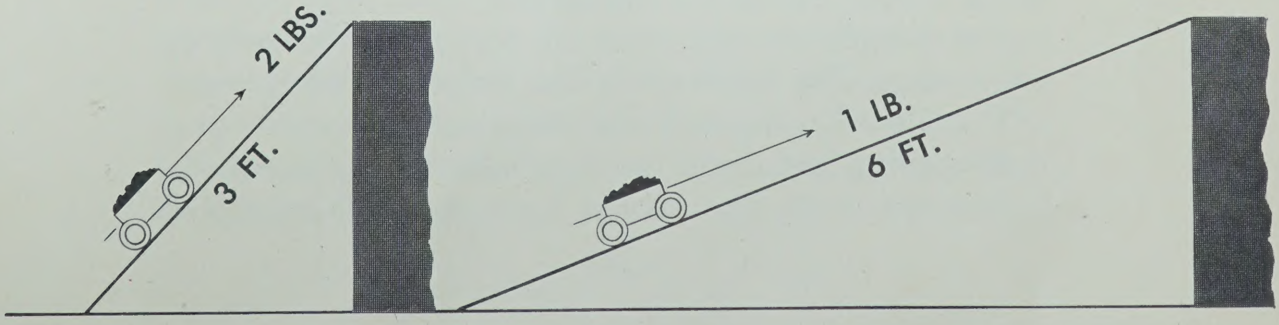
Perhaps the easiest thing to do would be to get a longer inclined plane. The slope would then be gentler, and the man would not need so much force to roll the barrel. But, of course, he would have to roll it farther. He would be trading more distance for more force.

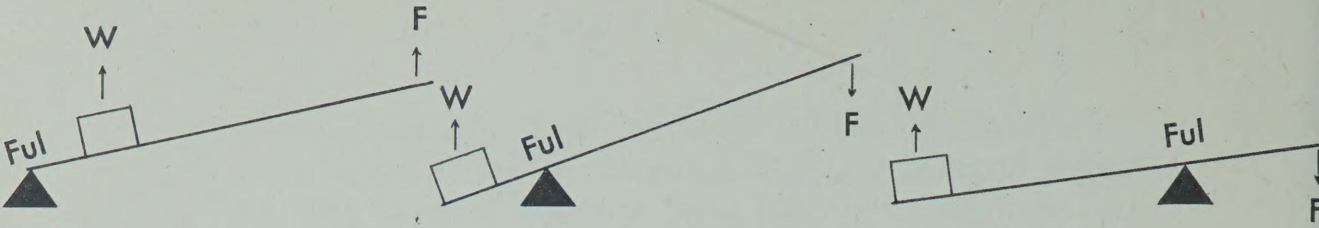
The diagram on this page shows that making a slope more gentle helps. It takes a force of two pounds to push or pull the little car up the first slope. It takes a force of only one pound to push or pull the car up the second slope. But notice that the second slope is twice as long.

It is easier to walk up a stairway from one floor to another than it is to climb a ladder that goes straight up and down. A stairway is an inclined plane. A stairway always slopes, but its slope is broken up into steps.

If you watch, you will be sure to see inclined planes being used. You are sure to see people walking up stairways. You will also see men wheeling wheelbarrows up sloping boards and using inclined planes to load and unload boats and trucks.

The inclined plane did not have to be invented. Any road up a hill is an inclined plane. Probably it did not take our early ancestors very long to find out that a steep slope is harder to climb than a gentle one. When they made this discovery, they had learned something about simple machines.





Levers

A cave man wanted a big stone to put in front of the door of his cave. He found a stone, but it was half buried in the ground. He could not lift it out. Near by he saw a dead branch that had fallen from a tree. He broke off the twigs. Then he pushed one end of the branch under the stone. He lifted the other end. Up came the stone. The cave man rolled it to the door of his cave.

This story may not be exactly true, but we know that people learned long ago how to pry up stones with sticks of wood. The first stick used to pry out a stone may have been the first lever ever made. For a stick that is used to pry out a stone is a lever. Jack used a screw driver as a lever, you remember, and pried the flag stick from the railing of the tree house.

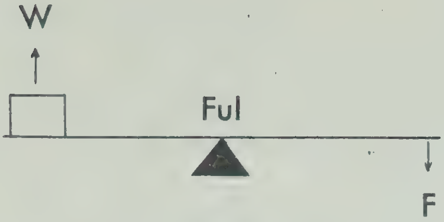
The first diagram at the top of the page is a diagram of the lever the cave man in the story used. It is also a diagram of the screw driver as Jack used it.

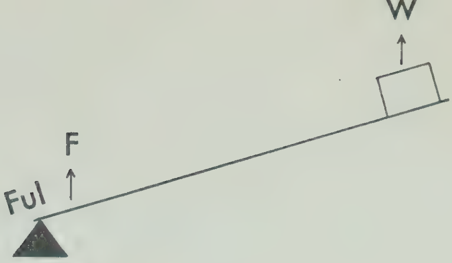
In the diagrams *F* stands for *force*. It shows you where the person working the lever pulled.

W stands for *weight*. It shows where whatever was being moved rested on the lever.

Ful stands for *fulcrum*. A lever has to rest on something. The fulcrum is the point where it rests.

The black triangle in the diagram may puzzle you. It is nothing but a sign to show where the fulcrum is. It does not mean that a lever has to rest on something





this shape. The fulcrum of the cave man's lever was where the stick rested on the ground. The fulcrum of Jack's lever was where the screw driver rested on the tree house railing.

The other diagrams at the top of these pages are diagrams of levers, too. In each one the force, the weight, and the fulcrum are marked.

The diagrams show that the fulcrum does not have to be at one end of the lever. It can be between the force and the weight. It may be exactly halfway between the force and the weight.

The force does not have to be at one end of the lever, either. It can be between the fulcrum and the weight.

In the same way, the weight can be between the fulcrum and the force or at one end of the lever.

The next three pictures show five levers. There is one lever to match each of the five diagrams you have just been looking at.

The post puller in the picture on the next page is very much like the lever the cave man in the story used. It is like the screw driver Jack used, too. It matches the first diagram.

The Boy Scout in the picture is prying up a stone with an iron rod, or crowbar. But his lever is not arranged like the one the cave man used. He has put one end of the crowbar under the stone, but the crowbar is resting on a small log. The log is the fulcrum. The boy is going to push down on the end of the crowbar he has in his hands.

This lever matches the second diagram on page 10. The fulcrum is between the force and the weight, and is much nearer the weight.

In the picture on the next page, the boy's fishing pole matches the third lever diagram. The forked stick is the fulcrum. When the boy pulls down on his end of the fishing pole, the other end will move up. Perhaps it will bring up a fish with it.

In this kind of lever the fulcrum is between the weight and the force. But it is nearer the force.

The girl's fishing pole matches the last lever diagram. Her left hand is the fulcrum. One end of the pole rests in it. When she catches a fish, she will give a jerk with her right hand. Then the other end of the pole will move up. In this lever, you see, the force is between the weight and the fulcrum.

The teeter-totter on page 14 matches the fourth of the lever diagrams. Here the fulcrum is exactly in the middle. The girl and boy weigh just the same. When she moves down, he goes up. When he moves down, she goes up.

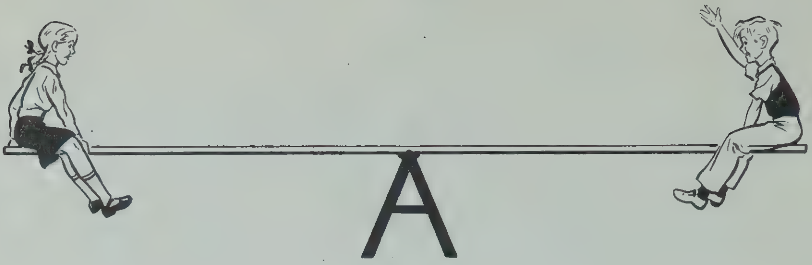
All inclined planes, you found out, gain force. Some levers do, too, but not all of them.

The man with the post puller, and the Boy Scout with the crowbar are gaining force with their levers. They could not pull up the post or lift the stone with nothing to help them. But notice that they have to move the ends of their levers a long way to lift the post and the stone a little way. They are trading distance for force, just as you do with an inclined plane.

The man pulling out the post is lifting up. The boy lifting the stone is pushing down. Before you arrange a lever, you have to decide whether you want to push on your end of it or pull.

When the boy who is fishing catches a fish, he has to move his end of the fishing pole down only a little way. The other end of the pole moves much farther and lifts the fish out of the water. But the boy has to use more force to lift a fish with his pole than it would take to lift the fish out of the water with his hands. He is trading force for distance.

Of course, if the end with the fish on it moves farther, it also moves faster. Whenever you gain distance with a simple machine, you gain speed, too.



The girl who is fishing is also trading force for distance. By moving her hand a little way, she flips her fish far out of the water. But she would not be strong enough to lift a really big fish with her pole.

In the teeter-totter, distance is not gained. The boy moves up just as far as the girl moves down. Then he moves down as far as she moves up. Force is not gained, either. She weighs 100 pounds, and so does he. It takes his whole weight of 100 pounds to lift her up. In the same way, it takes her whole weight of 100 pounds to lift him up. The only point to a lever with a fulcrum in the middle is that you can lift something up by pushing down.

How can you tell what you are going to gain if you use a lever? It is really very easy. The distance from the fulcrum to the force is called the *force arm.* The distance from the fulcrum to the weight is called the *weight arm.* Whenever the force arm is longer, you gain force. Whenever the weight arm is longer, you gain distance. If the two arms are the same length, you do not gain either force or distance.

Suppose you want to pry up a stone with a crowbar, just as the Boy Scout is doing in the picture. But you find that you cannot make the stone move. What can you do? Of course, you might get someone to help you. But suppose you have to move the stone by yourself. Then you can do either one of two things.

One is to get a longer crowbar. Then your force arm will be longer, and you will gain more force. If you get a crowbar that is long enough, you will be able to lift the stone.

The other is to move the fulcrum closer to the stone. Doing so also makes the force arm longer. Of course, it makes the weight arm shorter at the same time.

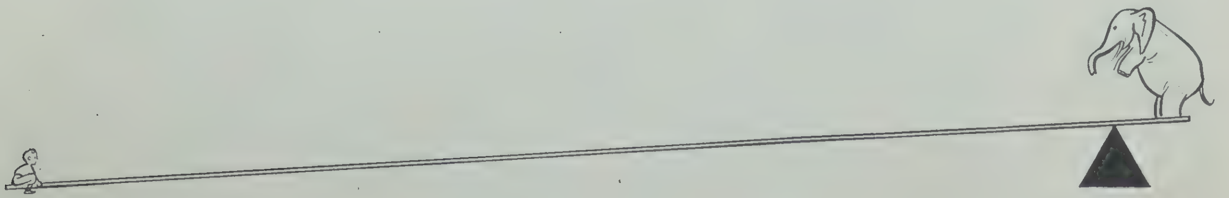
A thin boy can lift a fat one on a teeter-totter. All he has to do is to sit far enough away from the fulcrum. If the fat boy weighs twice as much as the thin boy, the thin one will have to sit twice as far away from the fulcrum.

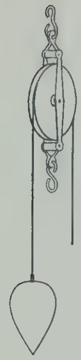
A boy could play teeter-totter with an elephant if he could find a teeter-totter that was long enough and strong enough.

Archimedes was a famous Greek scientist of long ago. He once said, "Give me a place to stand and a fulcrum of some kind, and I could lift the world with a lever." Anyone could. But think what a long, long force arm the lever would have to have!

If you want to gain more distance with your lever, you should make the weight arm longer. For example, if the girl's fishing pole were twice as long, she would lift the fish twice as far and fast when she gave the pole a jerk with her hand.

Levers are very common. Often they are combined with other simple machines. We shall find out more about combinations of machines later.





A

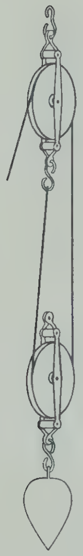
Pulleys

With their pulley Jack and Bob could raise their flag high above their heads. They could move it up by pulling down on one side of the loop of cord.

They did not gain any force by using the pulley. The flag weighed about a quarter of a pound, and the boys had to use a little more force than that to lift it up.

They did not gain any distance by using the pulley, either. To lift the flag up ten feet, the boys had to pull the other side of the loop down ten feet.

The pulley the boys used was a one-strand pulley. It was like *A* in the diagrams on this page. A one-strand pulley is like a lever with the fulcrum in the middle. You never gain either force or distance with it. But you can lift something up by pulling down, and being able to do so is often a help.



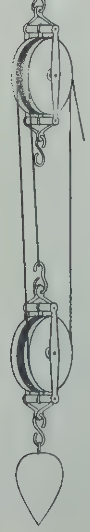
B

We call this kind of pulley a one-strand pulley because only one strand of rope is holding up the weight. The rope goes from the weight up over the pulley wheel. In the rim of the wheel there is a groove. The rope rests in the groove. The edges of the groove keep the rope from slipping off the wheel.

The boys used a *single pulley*. Often two or more pulleys are held together in a frame of wood or metal. A set of pulleys held together in this way is called a *pulley block*.

Single pulleys or pulley blocks can be joined to make *systems of pulleys*. In the diagrams on this page and page 17, *B*, *C*, *D*, *E*, and *F* are pulley systems.

All five of these arrangements of pulleys let us trade distance for force. With the right pulley system, one person can lift a very heavy load.



C

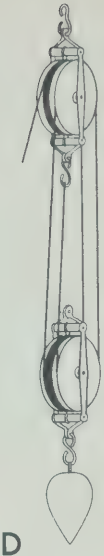
With a one-strand pulley, the thing to be lifted up is fastened to one end of the rope. In other arrangements of pulleys, the weight is hanging from the lower pulley or pulley block. One end of the rope is tied fast. Pulling on the other end of the rope lifts up both the weight and the lower pulley or block.

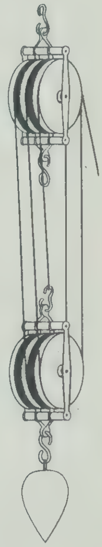
B, which is made up of two single pulleys, is a two-strand pulley system. There are two strands of rope holding up the load. If the weight and the pulley at the bottom together weigh 60 pounds, it would take a force of only about 30 pounds to lift the load with a pulley system like this. But you would have to pull the end of the rope two feet to lift the load one foot.

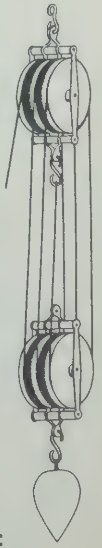
C is a three-strand pulley system. It is made up of two pulley blocks. Each one has two pulleys in it. Can you count the three strands of rope that help hold up the load? With this system you could lift a 60-pound load with a force of only about 20 pounds. But you would have to pull the end of the rope down three feet to lift the load one foot.

D is a four-strand pulley system. Can you see that there are four strands that help hold up the load? With a pulley system like this one you could lift a 60-pound load with a force of only about 15 pounds. But you would have to pull the end of the rope down four feet to lift the load one foot.

Do you understand now enough about pulleys to know how many strands there are in the pulley systems marked *E* and *F*? Can you tell about how much force it would take to lift a 60-pound load with each of these systems? Can you tell how far you would have to pull the rope of each one to lift the load one foot? From the table at the top of the next page you can find out whether you are right.


D


E


F

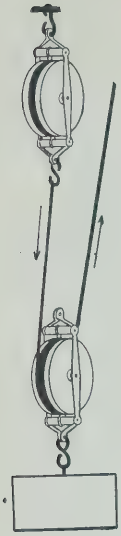
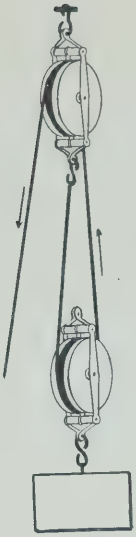
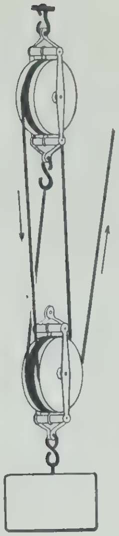
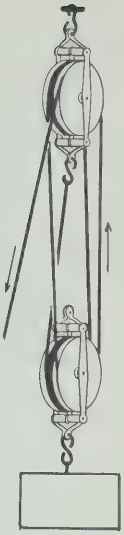
	How many strands?	About how much force will it take to lift a load of 60 lbs.?	How far do you have to pull the rope to lift the load one foot?
E	5	12 lbs.	5 ft.
F	6	10 lbs.	6 ft.

The picture on this page shows a *block and tackle.* You can see that it is a pulley system. Any pulley system may be called a block and tackle.

Suppose you were trying to lift a heavy box with a block and tackle but found that you could not pull hard enough. What change could you make in your block and tackle?

If in the two blocks there were any pulleys that were not being used, you could add more strands of rope. If all the pulleys were being used, you might find a block and tackle with more pulleys in each block.

Archimedes, you remember, said that he could lift the earth with a lever if he had the right kind of lever and somewhere to stand. He might have said that he could lift the earth with pulleys if he had a rope long enough and strong enough, enough pulleys, and something to hang them from.

You might think from the pictures that pulley systems are hard to arrange. But they really are not. The diagrams at the top of this page show you how to thread a four-strand pulley system.

If you will look carefully again at the diagrams on pages 16 and 17, you will find a way in which pulley systems with two, four, or six strands are different from pulley systems with three or five strands. One end of the rope is fastened to the upper block in the systems with an even number of strands. In the three- and five-strand pulley systems one end of the rope is fastened to the lower block.

All the diagrams on pages 16 and 17 show how to lift up a load by pulling down. But with all of these arrangements of pulleys except the first one you could lift the load by pulling up. You would not make the last strand of rope go over a pulley at the top.

Pulleys help lift big logs in forests. They help lift pianos up to the upper floors of buildings. They help load and unload ships. Painters use pulleys to lift up the scaffolding they work on when they paint tall buildings. Pulleys are very useful machines.

The Wheel and Axle

Probably you were puzzled when you found out that the windlass Jack and Bob used was a wheel and axle. You may not have been able to find any wheel in the picture of the windlass.

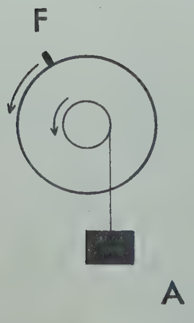
The crank of a windlass is the wheel. It is really only one spoke, but it works just the same as if it were a whole wheel. The rod the rope winds around is the axle. In a wheel and axle there is always a wheel or a part of a wheel and a rod or smaller wheel that turns around with it.

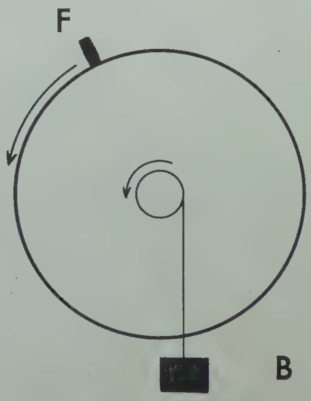
Windlasses used to be common in the country. They were used to lift pails of water from wells. They were used instead of pumps.

You might never guess that a doorknob is a wheel and axle. You might not even think of it as a machine. But it is a wheel and axle. The knob is the wheel. A wheel, you see, does not have to have spokes. The rod the knob is fastened to is the axle. The axle moves the catch of the door when you turn the knob.

It is easy to see that the steering wheel of an automobile is a wheel and axle. Each back wheel of an automobile (each drive wheel) is a wheel and axle, too.

The boys could lift a load easily with their windlass. The wheel—the circle the crank turned in as it moved around—was much bigger than the axle. The boys had to turn the crank all the way around to turn the axle





around once. They had to move the end of the crank about six feet to wind up a foot of rope and lift the load up a foot. With their windlass they were trading distance for force.

Suppose a driver of a big truck found that the steering wheel of the truck was very hard to turn. A wise thing for him to do would be to have a bigger wheel put on.

If Jack and Bob had found that they could not lift a load easily with their windlass, they could have made the crank longer.

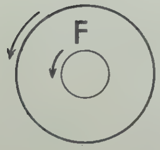
In the diagrams on page 20, *A* is a wheel and axle that saves force. So is *B*. It would be easier to lift a load of ten pounds with *B* than with *A*. The two axles are the same size, but the wheel in *B* is bigger. A wheel and axle with a big wheel and a small axle is like a lever with a long force arm and a short weight arm.

The wheel and axle marked *C* is not saving force. It is trading force for distance and speed. Here the axle is being turned, and it turns the wheel. Each of the back wheels of a car is like this. *D* is very much like *C*, but the wheel is bigger. A car would go faster if it had back wheels like *D* than if it had back wheels like *C*. It would go farther every time the axle turned around. But it would take more force to turn wheels like *D* than to turn wheels like *C*.

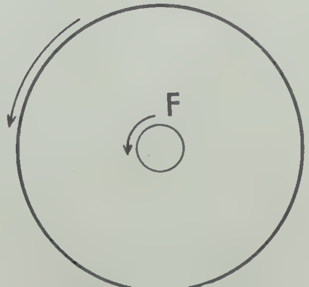
The two important things to remember about the wheel and axle are these:

When you make the axle turn by turning the wheel, you gain force.

When you make the wheel turn by turning the axle, you gain distance and speed.



C



D

The Wedge

You found out that the axe Bob used to cut down a tree was a wedge. The head of an axe has sloping sides. Every wedge has. A wedge is really two inclined planes put together.

When you use an inclined plane, you make something travel up and down it. When you use a wedge, you usually make it travel into something else. You could lift something heavy a little way by driving a wedge under it. But we do not often use wedges in this way. We usually use wedges to push things apart.

The boy in the picture at the top of the page is splitting a log with a wedge of wood. The farther he drives in the wedge, the farther he pushes apart the two halves of the log. At last the log will split in two.

Wedges let us gain force. You would expect them to because inclined planes do. Suppose the boy in the picture had a block of wood as wide as the top of his wedge but with sides that did not slope. He could not drive it down into the log. He would not be strong enough. But he can drive in the wedge.

On the next page there are two diagrams of wedges. They are just the same width at the top. But *B* is longer. Its sides have more gentle slopes. *B* could be driven into anything more easily than *A*. But you would have to drive it in farther.

With any wedge you trade distance for force. Even with the wedge marked *A* you would have to drive it in an inch to push the wood at the sides of it a quarter of an inch apart. You would have to drive *B* in two inches to push the wood a quarter of an inch apart.

Many of our common tools are wedges. The pictures at the bottom of the page show some of them.

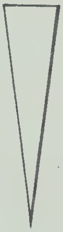
Did you ever think of a needle as a machine? Needles are machines. They are wedges. If you have ever tried to sew with a needle without a point, you know that the sharp point of a needle saves force.

Knives are wedges. The girl in the picture on page 35 would probably be surprised if you told her that she was cutting her cake with a wedge. But she is.

Sometimes the sharp edge of a wedge wears off. The two inclined planes do not come together. Then the wedge has to be sharpened so that the two planes will meet each other. Could you draw a diagram to show the difference between a sharp knife and a dull one?

Thousands of years ago people learned to use wedges. Back in the Old Stone Age men made knives and saws of stone. They did not understand that these tools let them trade distance for force. But they did know that with them they could cut things that they could not pull or tear apart.

Later, men learned to make tools of metal. They could make much better wedges of metal than of stone. Our best wedges of today are made of metal. They are made of special kinds of steel.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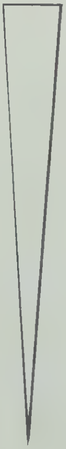
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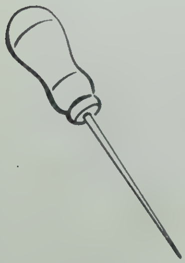
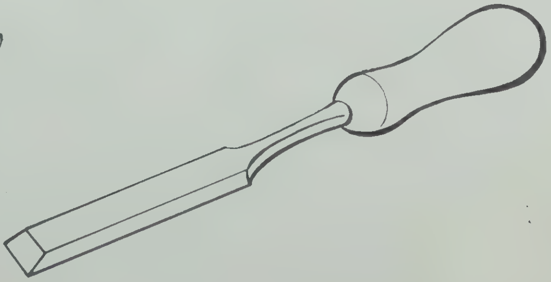




The Screw

A screw is an inclined plane that winds around instead of going straight. A stairway that winds up to the top of a tower is a screw. So is a road that winds up a mountain.

When you hear the word "screw" you probably think of a common screw like the one marked *A* in the picture. This screw does not look very much like a road winding up a mountain, but, if you look closely, you will see that there is a "road" winding around and around the center of the screw. This "road" is called the "thread" of the screw.

The picture at the bottom of page 25 will help you understand that a screw is an inclined plane. A piece of paper is being wound around a screw. The piece of paper has one sloping edge. As the paper is wound up, this edge makes a line like the thread of a screw.

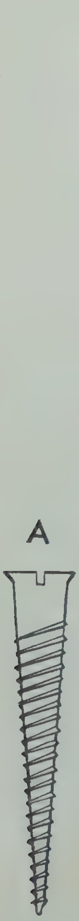
A screw may be used like a common inclined plane. A load may be pushed or pulled up it. Or it may be used like a wedge. It may be made to move into or through something.

A screw helps in just the same way that an inclined plane and a wedge help. It lets us trade distance and speed for force.

Jack and Bob used a clamp to hold their windmill in place. They had to turn the screw around and around many times to move it up a short way. But when it was moved up far enough, it held the windmill in place very firmly. The boys had traded distance for force.

The two screws marked *A* and *B* in the pictures on this page are the same size, but they are different in

A



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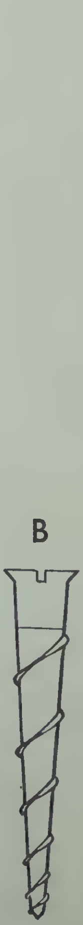
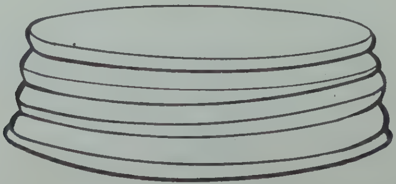




one important way. The threads are much closer together on *A* than on *B*. Can you tell which screw would go into a piece of wood more easily?

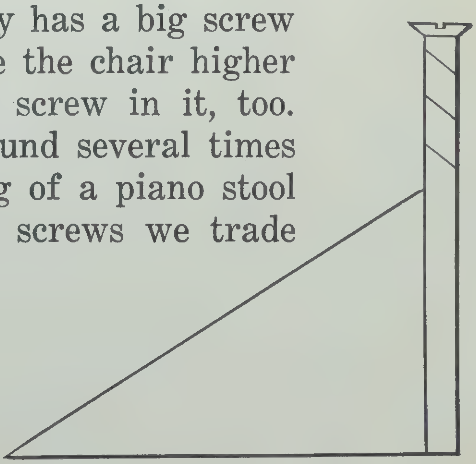
The one marked *A* would go in more easily. But it would have to be turned around more times. If you could unwind the threads on these two screws and lay them out flat, you would see that the one on *B* makes a shorter, steeper slope than the one on *A*.

You are sure to find several kinds of screws in your tool box. A bolt with threads around it is a screw. When you put the nut on the end of a bolt, you make it travel up the winding road of the screw. Part of a vise is a screw. The bit of your brace and bit is a screw. You may have several more.

The propeller of an airplane is a screw. Some boats have screw propellers. One picture at the bottom of page 24 shows the screw top of a glass fruit jar.

It is easy to pry the lid off a wooden box if the lid is nailed on. It is much harder to pry the lid off if it is screwed on. Screws are very often used to hold things together. In the room where you are now, you are sure to find many screws being used. Some of the wood that we use in our buildings is so hard that nails cannot be driven into it easily. Screws can be put into it much more easily.

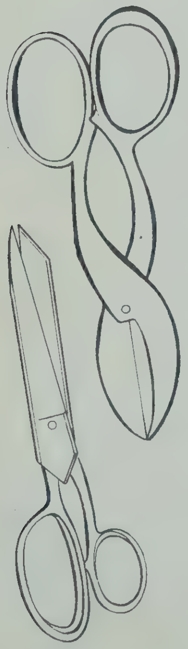
Your father's desk chair probably has a big screw in it. This big screw lets him make the chair higher or lower. A piano stool has a big screw in it, too. A piano stool has to be turned around several times to make it go up an inch. Thinking of a piano stool will help you remember that with screws we trade distance for force.



Two or More in One

The pictures on this page and on the next two pages show several common machines. All of them are combinations of simple machines. There are two or more simple machines in each one.

A common pair of scissors is a combination of two levers, two wedges, and a screw. Each half of the pair of scissors is a lever. The fulcrum is the screw that holds the two halves together. The cutting edges of the blades are wedges.

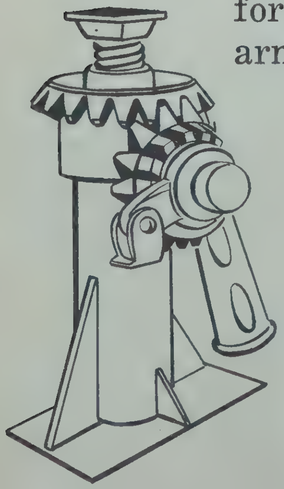


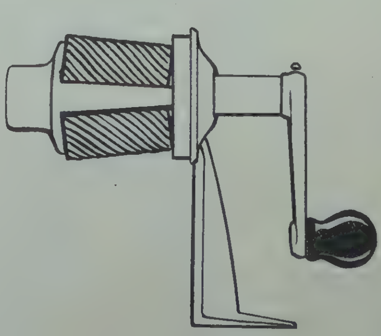
Metal shears have long handles and short blades. Do you see why? The long handles are the force arms. You cannot cut metal with common scissors unless the metal is very thin. The scissors must have handles long enough to let you gain a great deal of force.

Pruning shears have very long handles. Scissors of this kind are used to cut small branches off trees and bushes. The handles have to be long because small branches are likely to be tough and hard to cut.

Paper shears are quite the opposite of pruning shears and metal shears. Their blades may be longer than their handles. Paper is easy to cut. For cutting paper you do not need to gain force.

If you were trying to cut a piece of heavy wire in two with a pair of metal shears, where would you hold the wire? If you understand about levers, you would put it as near the fulcrum as you could. Then the force arms would be many times as long as the other arms. You would gain a great deal of force.





Of course, with any kind of scissors the sharpness of the wedges counts, too. It would not do much good to have long handles on a pair of metal shears if the blades were very dull.

A drill like the one on page 26 is a combination of a wheel and axle and a screw. The wheel and axle shows plainly. The wheel has one spoke. The axle is a smaller wheel that has teeth around the edge. A wheel like this is called a *gear wheel.* The bit is the screw.

There are different kinds of automobile jacks. The one pictured is a combination of a lever and a screw. With a jack like this a person can lift a heavy weight. But the jack lifts the weight very slowly.

A pencil sharpener like the one in the picture is made up of a wheel and axle, two screws, and two wedges. The handle is the wheel and axle. It is a wheel with only one spoke. Inside the sharpener there are two screws with threads that have sharp edges. The edges are wedges. Turning the handle turns the screws around and around. The wedges shave off thin bits of wood and lead. They sharpen the pencil.

The man in the picture at the top of this page is using a scythe. A scythe is a combination of a wedge and a lever. The blade, of course, is a wedge. The handle is a lever like the last diagram on page 11. The man's left hand is the fulcrum. He does the pushing and pulling with his right hand. Every time he moves his right hand a foot, the blade of the scythe moves several feet.

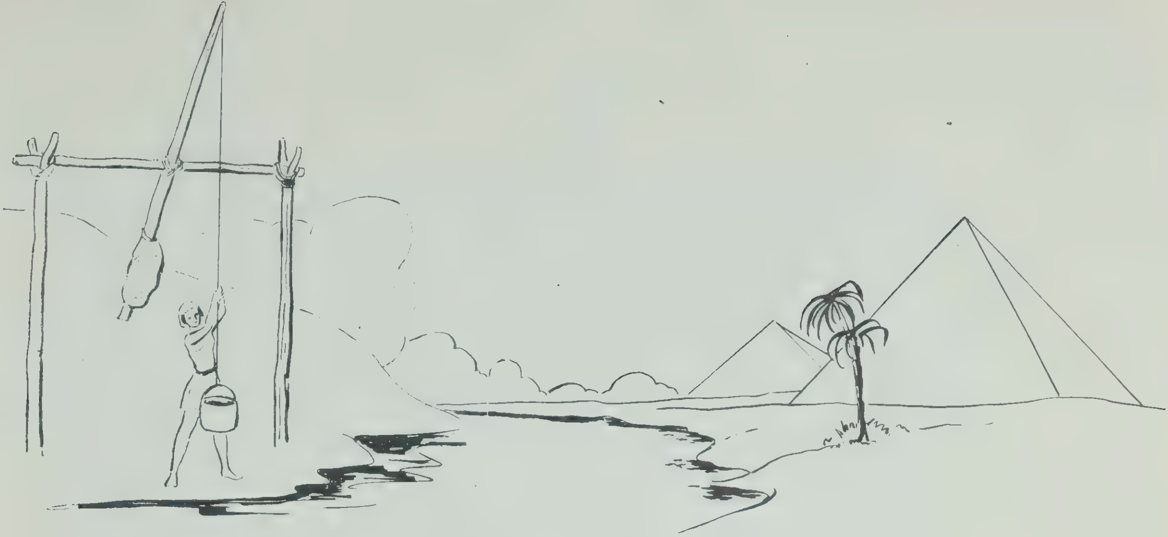
A pitchfork is made up of the same kinds of simple machines a scythe is made up of. So is a spade.

In your kitchen you are almost sure to have a food grinder. This machine is very much like a pencil sharpener. The handle is a wheel and axle. Inside the grinder there is a screw. The screw pushes the food against some sharp wedges that cut it into pieces.

In an eggbeater each set of blades is a wheel and axle. You turn them by turning a gear wheel. The blades of the eggbeater go around much faster than your hand moves.

A bicycle is made up of more than one wheel and axle, too. The pedals make one wheel and axle. The back wheel and its axle make another. You turn the pedals around. A chain connects them with the back wheel. The bicycle moves much farther than your feet move. The handle bars are a part of a third wheel and axle. They make up a wheel with two spokes.

There are many, many other machines that are combinations of simple machines. Even with these combinations of machines, you cannot gain both force and distance at the same time. You always have to trade one for the other.



Servants That Help Us Work

The boy in the picture on this page is an Egyptian boy. He is using a shadoof. He is using it to help him lift water from the river to pour on the fields.

A shadoof is a lever. When one end is pushed or pulled down, the other end goes up.

The bucket is at one end of the lever. Fastened to the other end there is a big lump of dried mud. The lump of mud is heavy. It holds the bucket up out of the water when the bucket is empty.

The boy uses the shadoof in this way. He pulls the bucket down so that it is in the water. Of course, as he does so, he has to lift up the lump of dried mud. But notice that the fulcrum is nearer the end of the lever that has the mud weight on it. It is not hard for him to lift the weight.

As soon as the bucket is full, he pulls up on it. The bucket full of water is heavy. He could not lift it easily. But the mud weight helps him. It does much of the lifting for him.

Shadoofs have been used for many hundreds of years. The person who invented the shadoof long ago found out that he could use a weight to help him run a machine.

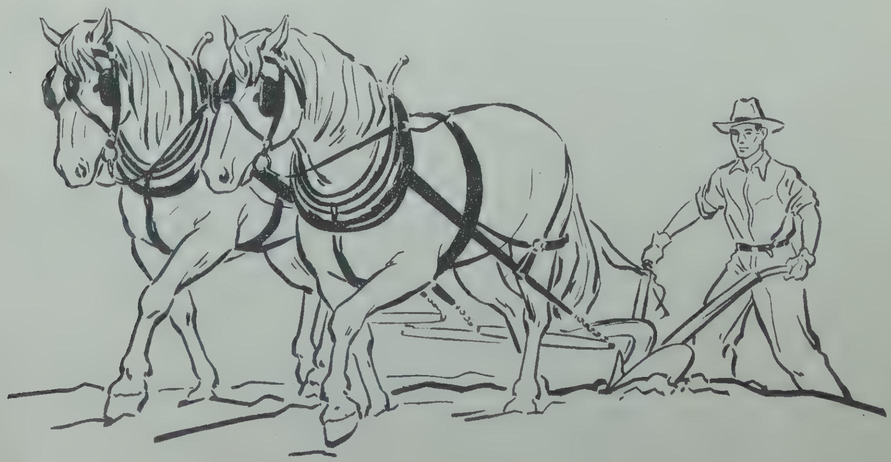
In your house you probably have windows that open by moving up and down. Heavy weights help you raise such windows. The weights are hidden in the window frames. Cords from them go up over little pulleys at the tops of the windows. The weights are not quite heavy enough to lift the windows by themselves. But they are heavy enough to help you a great deal when you raise a window.

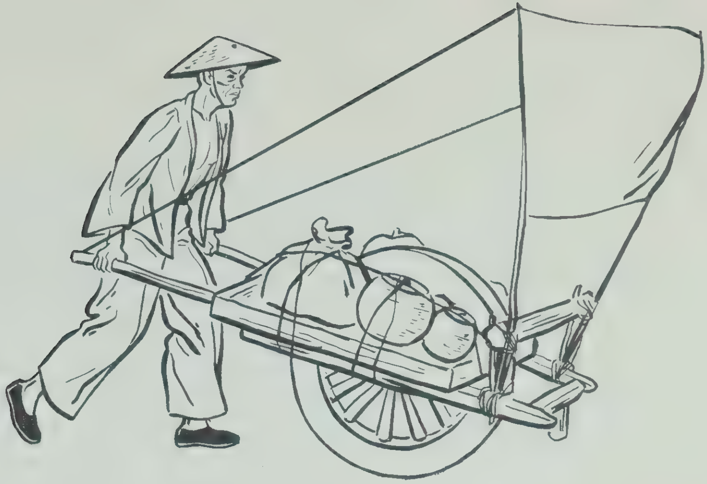
Back in the days of the cave men, people began taming animals. They wanted the animals for pets or for food. But later they found that some of their tame animals could help them work.

We still use animals to help us work. In the picture on this page the horses are pulling a plow. A plow is a machine. It is a wedge.

We can use wind to help us run our machines. Probably you have seen windmills pumping water. The handle of a common pump for lifting water out of a well is a lever. A person can do the pumping by hand, but he saves himself a great deal of work by letting the wind work the lever for him.

A wheelbarrow is a lever, too. The fulcrum is where the wheelbarrow is fastened to the wheel. A person can lift a rather heavy load with a wheelbarrow because the force arm is longer than the weight arm. The wheel makes it easy for him to push the load along.





The Chinese in the picture is making the wind help him push his wheelbarrow. The sail catches the wind.

An airplane propeller, you already know, is a screw. The propeller screws its way through the air and pulls the plane with it. But no one could turn the propeller fast enough to make the plane fly. You may have made toy airplanes that you worked with rubber bands. You twisted the rubber bands so that they were like wound-up springs. Then they untwisted and turned the propeller. In a real airplane a big gasoline engine takes the place of the rubber bands. Automobiles and many other machines are run by gasoline engines, too.

We use moving water to run some of our machines. The water turns big water wheels, and these wheels turn other machines.

Steam does a great deal of work for us. It runs many of our machines. It runs most of our big locomotives. It runs many of the machines in our factories, too.

Electricity is another of our helpers. It runs many of the machines in our factories. It also runs electric fans and other machines in our houses.

Wind, water, steam, gasoline, weights, springs, tame animals, and electricity—we can think of all of these as servants that help us work. They help us run our machines.

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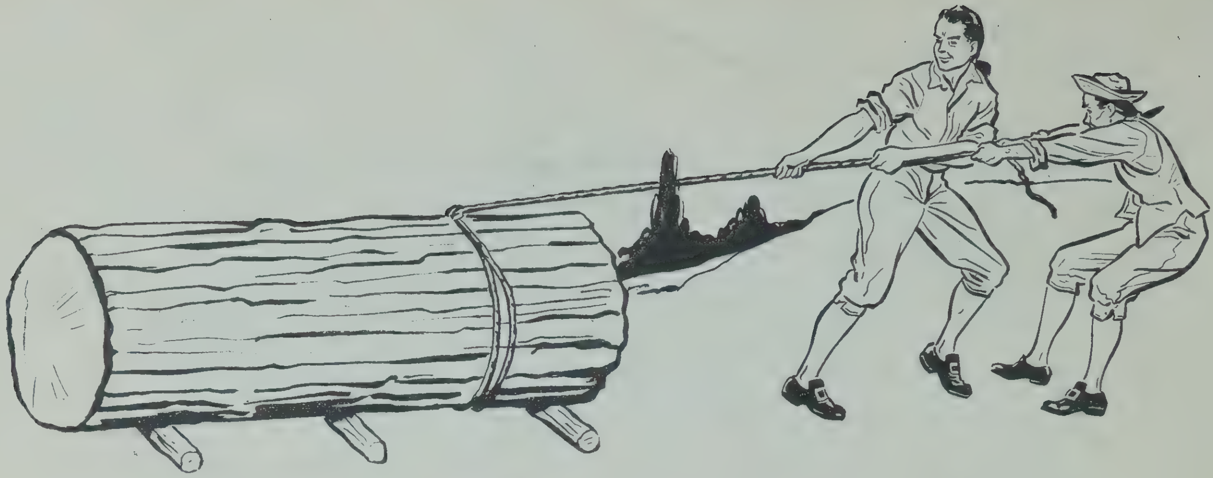


Friction

Jack and Bob, you remember, pulled their wooden chest up an inclined plane to their tree house. They pulled it up easily. But they could not have pulled it up so easily if it had not had rollers at the corners. If it had not had rollers, there would have been a great deal of *friction* between the bottom of the chest and the boards in the inclined plane.

"Friction" comes from a word that means "rub." There is friction whenever two things rub together. If there is a great deal of friction, it may take a great deal of pushing or pulling to overcome it.

Thousands of years ago people learned that rollers help make friction less. Probably the first rollers were logs. Perhaps they were much like the small logs that are being used as rollers in the picture on this page.

From using logs as rollers people got the idea of wheels. The big wheels of carts and wagons and railway cars help by making friction less.

Ball bearings are rollers of another kind. Probably you have ball bearings in your roller skates.

There is some friction in every machine when it is being used. If you will look again at page 17, you will find a great many "abouts" on that page. You can tell by counting the strands of a pulley system *about* how much force you will need to lift a certain weight with it. But you cannot tell *exactly* how much, for you cannot tell how much friction there is in the pulley system. If you were to use small pulleys and heavy ropes, there might be so much friction that the pulley system would not help you much.

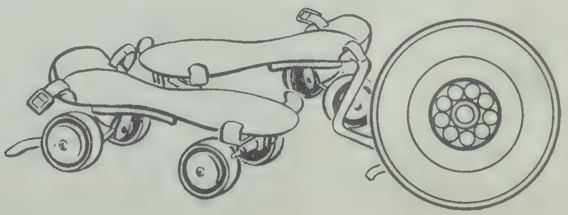
No one could make a very good guess about how much force it would take to drive the wedge you see in the picture on page 22 into the log. There would be a great deal of friction between the wedge and the log.

There is not so much friction between smooth surfaces as there is between rough ones. One way of making a surface smooth is to put oil on it. The boy in the picture on the next page is oiling his bicycle so that there will not be so much friction in it.

Friction produces heat. If you make a hole through a thick piece of hard wood with a drill, the drill will be hot. Sometimes one of the wheels of a train has a "hotbox." A hotbox is caused by too much friction. There is not enough grease in the hub of the wheel. The friction sets the grease there is in the hub on fire.

If there were no friction, it would be much easier to drill a hole through a board than it is now. It would take less force to push or pull a load up an inclined plane than it does now. You would not need to put rollers under it. The treads on rubber tires would never wear off. You would never wear holes in the soles of your shoes. There would be no need for machine oil or axle grease.

Did you ever hear of a perpetual motion machine? There is no such machine, but many people have tried to invent one. A perpetual motion machine is one that

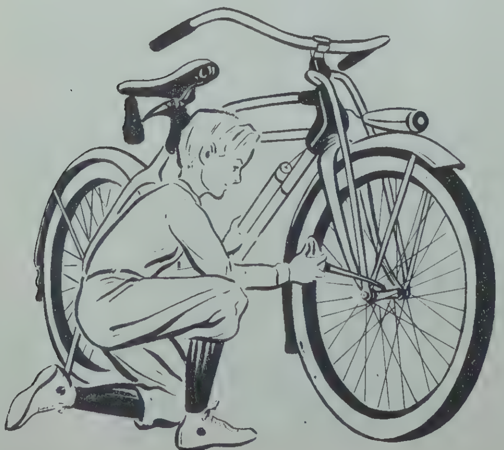


would keep going forever after it was started unless someone stopped it. Such a machine is impossible because there is no way of getting rid of all friction. Sooner or later friction would make any machine stop unless it was given a fresh start every so often. Even if you kept giving it a new start, it would stop at last because friction would make it wear out.

You might think for a minute that it would be a good thing if there were no friction. But if you could try shutting off all friction, you would soon change your mind.

You could not walk if there were no friction. The floors and sidewalks and ground would be more slippery than smooth ice. You could not go anywhere in a car or a train. The wheels would spin around and around where they were. Nails would not hold anything together. You could drive them in easily, but they would soon come out. You could not lift a weight with a pulley. Your hands would slip off the rope.

You could not write with a lead pencil. None of the lead would rub off on your paper. You could not rub out a pencil mark. You could not strike a match. No one could tie a knot that would stay tied. Friction makes us use more force to run our machines, and it makes our machines wear out. But you are sure to agree that it is often a help.



Do You Know Now?

1. Machines make work easier.

2. There are six kinds of simple machines. They are the inclined plane, the lever, the pulley, the wheel and axle, the wedge, and the screw.

3. With some of these machines we can move an object in one direction by pushing or pulling in some other direction.

4. With some simple machines we can gain force.

5. With some simple machines we can gain distance and speed.

6. We cannot gain force and distance and speed at the same time with any simple machine.

7. If distance and speed are gained, force is lost.

8. If force is gained, distance and speed are lost.

9. Many machines are combinations of two or more simple machines.

10. People have learned to use other animals to help them run machines.

11. People have also learned to use weights, springs, electricity, steam, gasoline, running water, and wind to run machines.

12. There is some friction in all machines.

13. People have found several ways of making friction less.

See for Yourself

1. Find examples of the six kinds of simple machines.

2. On the inside covers there are pictures of many machines. Try to tell what kind of machine each one is. Some of the machines are made up of more than one simple machine.

3. Get a strip of wood about three inches wide and three feet long to use as a lever. For a fulcrum get a piece of wood shaped like a triangle. Arrange the lever in one after another of the five ways shown on pages 10 and 11 and lift a weight with it. Do you agree with the third paragraph on page 14?

4. Arrange a one-strand pulley. Arrange also a two-strand, a three-strand, a four-strand, a five-strand, and a six-strand pulley system. Use one after the other to lift a weight. With which one is it easiest to lift the weight? With which one do you have to pull the rope farthest to lift the weight a foot?

5. Arrange a board so that it makes an inclined plane. Pull a small loaded car up the slope. Use a spring balance to find out how much force you have to use to pull the car up. Now get a longer board and put it in place of the first board. The slope will not be so steep. Pull the car up the slope. How much force does it take?

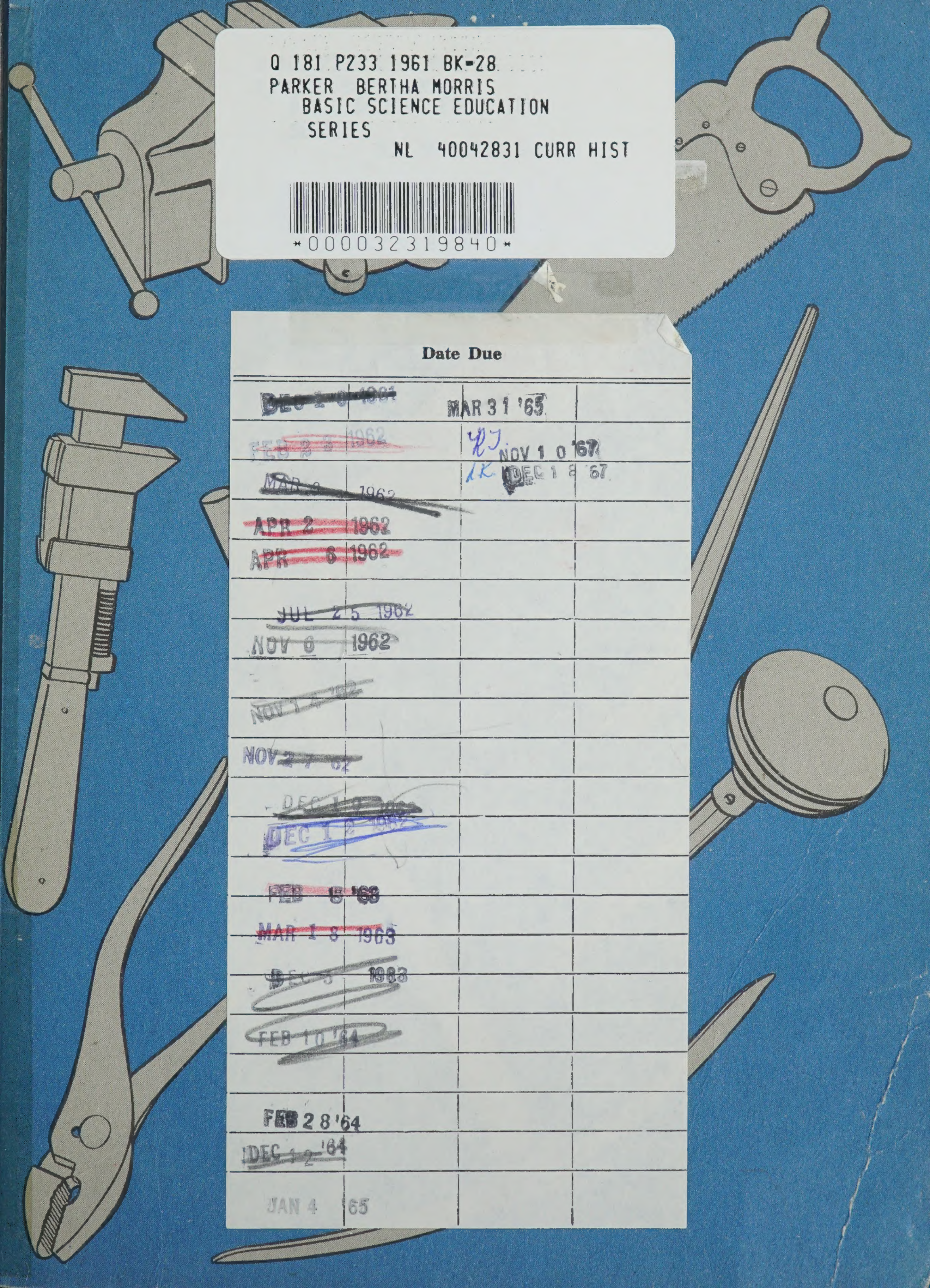
6. Use a dry cell to run a toy electric motor. Make the motor turn some other toy.

7. Use the water from the faucet to turn a toy water wheel. Make the water wheel turn some other toy.

8. Run a toy steam engine. Make the steam engine turn some other toy.

9. Set a toy windmill where the wind will strike it. Watch the wheel turn around.

Illustrations by GEORGE SARGENT



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